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An Adaptive JPEG Image Compression Using Psychovisual Model

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JPEG baseline coding is a popular basic image compression technique. The JPEG-3 image compression is an extension of standard JPEG image compression which uses a quality factor to scale quantization table. In order to achieve high compression rate, the JPEG-3 image compression uses lower quality factor. The lower bit rates of image compression using scaling factor will degrade the visual quality on the images being compressed. This paper proposes a high compression scheme based on psychovisual threshold as an adaptive image compression. The comparison between JPEG-3 image compression using the typical quality factor and an adaptive psychovisual threshold has been done. The experimental results of an adaptive quantization tables based on psychovisual threshold show an improvement on the quality image reconstruction at the lower average bit length of Huffman code.

Keywords: Image Compression, Psychovisual Threshold, JPEG Quantization Tables.

1. INTRODUCTION

A digital image camera captures, compresses and stores in real time[1,2]. JPEG image compression is the popular method used in digital cameras[3]. It performs relatively well utilizing low computation and memory storage. The compression rate is mainly determined by the quantization tables and entropy coding. Recently, the popular extended JPEG allow a user to choose output preferences according to the quality factor *QF* to scale the quantization tables. The image compression engine typically will use the quality factor to scale quantization tables which may not be optimal to the output image quality.

In order to achieve high quality image compression at low bit of image, the quantization table may need to be designed based on human visual system properties. This paper proposes an adaptive psychovisual threshold to provide custom quantization tables based on the concept of psychovisual threshold.

Several approaches have been conducted to investigate the psychovisual models such as human visual weighting[4] and psychovisual model based on preserving downsampling and upsampling[5]. In general, a psychovisual model has been designed based on the understanding of brain theory and neuroscience[6]. This paper will investigate the contribution of each DCT coefficient to the image reconstruction. The error threshold from the image reconstruction will be the primitive to the psychovisual threshold proposed in this paper.

The organization of this paper is as follows. The next section provides a brief description of the discrete cosine transform. Section 3 presents the experimental design on generating an adaptive psychovisual threshold. The new quantization table generatd from psychovisual thresholds are presented in Section 4. The experimental results of the JPEG image compression using quality factors and the proposed quantization table based on adaptive psychovisual threshold are given in Section 5. Lastly section 6 concludes this paper.

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2. DISCRETE COSINE TRANSFORM

The definition of the two-dimensional DCT is given as follows[7]:

$$B_{pq} = \alpha_p \beta_q \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} A_{mn} \cos\frac{\pi(2m+1)p}{2M}\cos\frac{\pi(2n+1)q}{2N},$$

for p = 0, 1, 2, …, M-1 and q = 0, 1, 2, …, N-1.

where

$$\alpha_p = \begin{cases} \frac{1}{\sqrt{M}}, & p = 0 \\ \sqrt{\frac{2}{M}}, & p > 0 \end{cases} \qquad \beta_q = \begin{cases} \frac{1}{\sqrt{N}}, & q = 0 \\ \sqrt{\frac{2}{N}}, & q > 0 \end{cases}$$

Each frequency coefficient B_{pq} carries the frequency order $p+q$. The inverse of two-dimensional DCT is given as follows:

$$A_{pq} = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} \alpha_p \beta_q B_{mn} \cos\frac{\pi(2m+1)p}{2M}\cos\frac{\pi(2n+1)q}{2N},$$

for p = 0, 1, 2, …, M-1 and q = 0, 1, 2, …, N-1.

3. AN EXPERIMENTAL DESIGN

A quantization table limits the sensitivity of the human visual system on the image information. The irrelevant image information is removed by the quantization table during the quantization process of JPEG image compression. Most of the time, the quantization will remove the high frequency signals and discard information which is not visually significant to image. The JPEG quantization tables on luminance Q_{CL} and Q_{CR} chrominance are provided as follows:

$$Q_{CL} = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

$$Q_{CR} = \begin{bmatrix} 17 & 18 & 24 & 47 & 99 & 99 & 99 & 99 \\ 18 & 21 & 26 & 66 & 99 & 99 & 99 & 99 \\ 24 & 26 & 56 & 99 & 99 & 99 & 99 & 99 \\ 47 & 66 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \end{bmatrix}$$

The extended JPEG compression introduces a simple and efficient method to produce quality compression levels known as a quality factor QF. The QF is the quality reference number which ranges from 1 to 100[8]. The QF is then used to scale the quantization tables by a weighting factor w as follows:

$$w = \frac{50}{QF} \quad for\ QF < 50$$

$$w = 2 - \frac{QF}{50} \quad for\ 50 \le QF < 100$$

where QF <50 yields high compression rate, whereas the QF >50 produces the higher quality output image possible Typically, the quality factors 25, 50 and 75 are set to obtain output image with low, medium and high qualities respectively. The quantization steps are defined by rounding to the nearest integer:

$$T_{pq} = Round\left(\frac{B_{pq}}{w \cdot Q_{pq}}\right)$$

Dequantization is the inverse function by multiplying the coefficient in each block using the same quantization matrix Q_{pq}[9]. The dequantization is defined as follows:

$$B_{pq'} = T_{pq} \cdot w \cdot Q_{pq}$$

The key issue on achieving high compression performance is the generation of a lower average bit of Huffman code will imply the lower image reconstruction quality which produces artifacts on the output image. Some distortion will clearly appear in the reconstruction image such as blocking artifact, ringing artifact and blurring[10]. Blocking artifact arise at high compression ratios and very low quality factors. In order to reduce the artifacts on the output image at high quality image reconstruction, it is desirable to consider the characteristics of human visual system.

This paper presents a quantitative experimental impact on image compression based on the concept of psychovisual threshold. The 80 images (24-bit RGB with 512×512 pixels) are chosen for this quantitative experiment. The 80 images are classified into two categories which are 40 real image and 40 graphic images. First, the RGB color components are converted into luminance and chrominance. Next, the images are divided into the 8×8 size blocks and each block of the image data is transformed by a 2-dimensional DCT. The resulting DCT coefficients are incremented one by one up to a maximum order quantization table value. The effects of an increment on DCT coefficients are measured by the image reconstruction error.

4 EXPERIMENTAL RESULTS

An adaptive psychovisual threshold on generating quantization tables is investigated for a high bit rate compression. In order to optimize the JPEG performance at high rate compression, quantization tables are designed by optimizing the visual quality of the reconstructed image at a given bit rate. The average full error score for 40 natural color images is calculated by image reconstruction error measurement. The average image reconstruction error score of incrementing DCT coefficients on luminance and chrominance for 40 natural images are shown in Figure 1 and Figure 2.

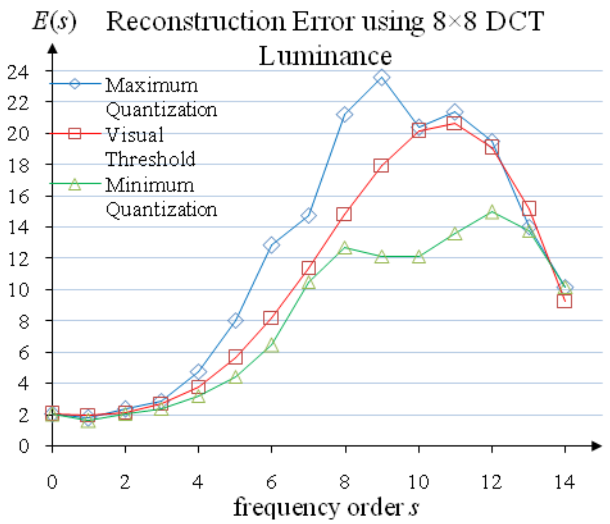

Fig.1. Average reconstruction error of an increment on DCT coefficient Luminance for 40 natural color images.

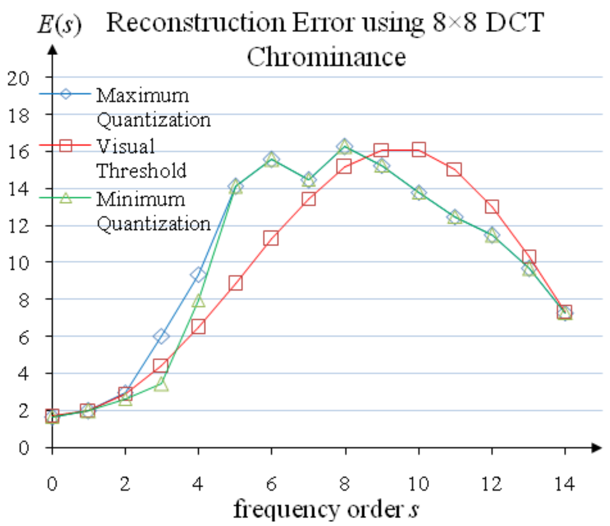

Fig.2. Average reconstruction error of an increment on DCT coefficient Chrominance for 40 natural color images.

The effect of an increment within the minimum and maximum quantization table values from an order zero to the order fourteen produces a curve. The green line represents image reconstruction error based on a minimum of the quantization table value and the blue line represents image reconstruction error based on a maximum quantization table value. In order to produce a psychovisual threshold, the new average target on reconstruction error is set as a smooth transition curve which results in an ideal curve of average reconstruction error as presented by a red line. The smooth reconstruction error curves represent psychovisual thresholds for luminance f_{VL} and chrominance f_{VR} which are defined as follows:

$$f_{VL}(x) = 0.00005715x^6 - 0.002x^5 + 0.0202x^4 - 0.0561x^3 + 0.1683x^2 - 0.1743x + 2$$

$$f_{VR}(x) = 0.0002785x^5 - 0.0082x^4 + 0.0471x^3 - 0.2082x^2 + 0.0588x + 1.7$$

for $x = 0, 1, 2, ..., 14$.

In order to generate adaptive quantization tables, these functions are weighted according to target quality factors. The authors propose the following functions which will be used to generate the adaptive quantization tables.

$$f_{VLA}(x) = (0.00005715 + 0.0000000846\alpha)x^6 - (0.002 + 0.0000027\alpha)x^5 + (0.0202 + 0.000042\alpha)x^4 - (0.0561 + 0.00066\alpha)x^3 + (0.1683 + 0.00552\alpha)x^2 - (0.1743 - 0.0168\alpha)x + 2$$

$$f_{VRA}(x) = (0.0002785 + 0.00000036\alpha)5x^5 - (0.0082 + 0.00003\alpha)x^4 + (0.0471 + 0.00048\alpha)x^3 - (0.2082 - 0.0033\alpha)x^2 + (0.0588 + 0.0375\alpha)x + 1.7$$

where α is a scale factor *SF* for visual error threshold and x is the frequency orders from 0, 1, ..., 14. The new scale factor *SF* value for psychovisual threshold ranges from -25 until 25. The larger scale factor *SF* is the high compression ratio. These functions f_{VLA} and f_{VRA} are depicted in Figure 3 and Figure 4 with scale factor *SF*= -25, 0 and 25 respectively for luminance and chrominance.

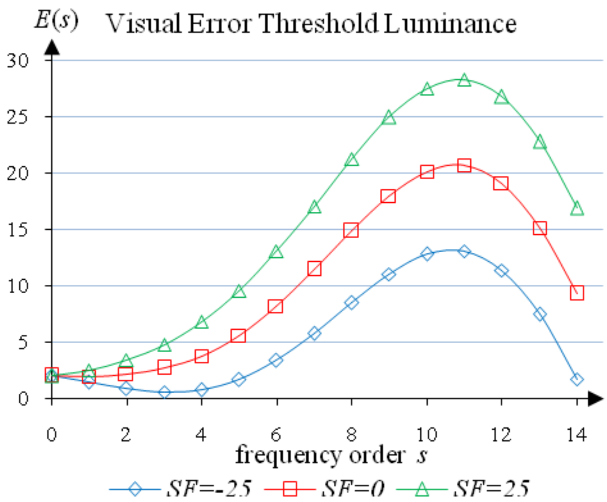

Fig.3. Average reconstruction error of an increment on DCT coefficient Luminance for 40 natural color images with *SF*= -25, 0 and 25.

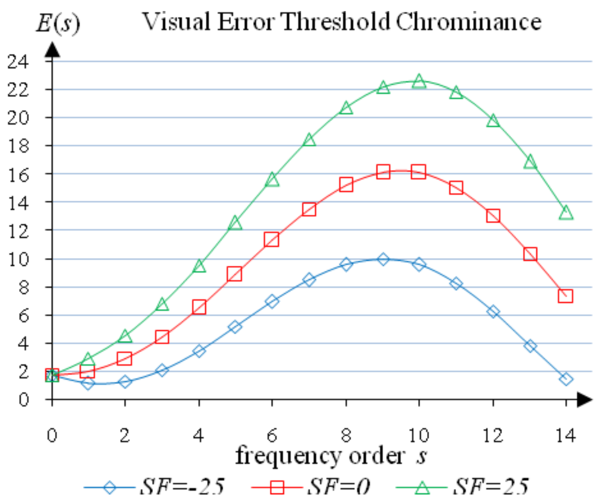

Fig.4. Average reconstruction error of an increment on DCT

coefficient Chrominance for 40 natural color images with *SF*= -25, 0 and 25.

Based on these functions f_{VLA} and f_{VRA}, the new quantization tables are generated according to scale factors -25, 0 and 25 as follows:

$$Q_{VLA1} = \begin{bmatrix} 16 & 10 & 5 & 3 & 3 & 8 & 15 & 28 \\ 10 & 5 & 3 & 3 & 8 & 15 & 28 & 37 \\ 5 & 3 & 3 & 8 & 15 & 28 & 37 & 51 \\ 3 & 3 & 8 & 15 & 28 & 37 & 51 & 65 \\ 3 & 8 & 15 & 28 & 37 & 51 & 65 & 74 \\ 8 & 15 & 28 & 37 & 51 & 65 & 74 & 70 \\ 15 & 28 & 37 & 51 & 65 & 74 & 70 & 55 \\ 28 & 37 & 51 & 65 & 74 & 70 & 55 & 16 \end{bmatrix}$$

$$Q_{VRA1} = \begin{bmatrix} 18 & 9 & 9 & 15 & 24 & 35 & 43 & 57 \\ 9 & 9 & 15 & 24 & 35 & 43 & 57 & 58 \\ 9 & 15 & 24 & 35 & 43 & 57 & 58 & 64 \\ 15 & 24 & 35 & 43 & 57 & 58 & 64 & 75 \\ 24 & 35 & 43 & 57 & 58 & 64 & 75 & 65 \\ 35 & 43 & 57 & 58 & 64 & 75 & 65 & 53 \\ 43 & 57 & 58 & 64 & 75 & 65 & 53 & 38 \\ 57 & 58 & 64 & 75 & 65 & 53 & 38 & 18 \end{bmatrix}$$

$$Q_{VLA2} = \begin{bmatrix} 16 & 14 & 13 & 15 & 19 & 28 & 37 & 55 \\ 14 & 13 & 15 & 19 & 28 & 37 & 55 & 64 \\ 13 & 15 & 19 & 28 & 37 & 55 & 64 & 83 \\ 15 & 19 & 28 & 37 & 55 & 64 & 83 & 103 \\ 19 & 28 & 37 & 55 & 64 & 83 & 103 & 117 \\ 28 & 37 & 55 & 64 & 83 & 103 & 117 & 117 \\ 37 & 55 & 64 & 83 & 103 & 117 & 117 & 111 \\ 55 & 64 & 83 & 103 & 117 & 117 & 111 & 90 \end{bmatrix}$$

$$Q_{VRA2} = \begin{bmatrix} 18 & 18 & 23 & 34 & 45 & 61 & 71 & 92 \\ 18 & 23 & 34 & 45 & 61 & 71 & 92 & 92 \\ 23 & 34 & 45 & 61 & 71 & 92 & 92 & 104 \\ 34 & 45 & 61 & 71 & 92 & 92 & 104 & 115 \\ 45 & 61 & 71 & 92 & 92 & 104 & 115 & 119 \\ 61 & 71 & 92 & 92 & 104 & 115 & 119 & 112 \\ 71 & 92 & 92 & 104 & 115 & 119 & 112 & 106 \\ 92 & 92 & 104 & 115 & 119 & 112 & 106 & 100 \end{bmatrix}$$

$$Q_{VLA3} = \begin{bmatrix} 16 & 17 & 20 & 27 & 34 & 48 & 59 & 83 \\ 17 & 20 & 27 & 34 & 48 & 59 & 83 & 92 \\ 20 & 27 & 34 & 48 & 59 & 83 & 92 & 115 \\ 27 & 34 & 48 & 59 & 83 & 92 & 115 & 140 \\ 34 & 48 & 59 & 83 & 92 & 115 & 140 & 160 \\ 48 & 59 & 83 & 92 & 115 & 140 & 160 & 165 \\ 59 & 83 & 92 & 115 & 140 & 160 & 165 & 167 \\ 83 & 92 & 115 & 140 & 160 & 165 & 167 & 165 \end{bmatrix}$$

$$Q_{VRA3} = \begin{bmatrix} 18 & 27 & 37 & 53 & 67 & 88 & 99 & 126 \\ 27 & 37 & 53 & 67 & 88 & 99 & 126 & 126 \\ 37 & 53 & 67 & 88 & 99 & 126 & 126 & 144 \\ 53 & 67 & 88 & 99 & 126 & 126 & 144 & 162 \\ 67 & 88 & 99 & 126 & 126 & 144 & 162 & 174 \\ 88 & 99 & 126 & 126 & 144 & 162 & 174 & 172 \\ 99 & 126 & 126 & 144 & 162 & 174 & 172 & 174 \\ 126 & 126 & 144 & 162 & 174 & 172 & 174 & 181 \end{bmatrix}$$

These new quantization tables will be applied in JPEG image compression to measure the performance of the proposed custom quantization tables based on the concept of psycho visual threshold. The performances of image compression using psychovisual threshold are analyzed by the qualities of reconstructed image and the bit rate of compressed image.

5. ADAPTIVE IMAGE COMPRESSION SCHEME

According to JPEG standard, the input image is grouped 8×8 pixels blocks and each block is independently transformed using 2-dimensional DCT. The DCT coefficients are quantized and encoded. The average bit length of Huffman code based on quality factor *QF* and the proposed psychovisual threshold for DCT is shown in Table 1, Table 2 and Table 3.

Table.1. Average Bit Length of Huffman Code of JPEG Image Compression Using Quality Factor *QF*=75 and Psychovisual Threshold *SF*= -25.

Average bit length of Huffman Code	JPEG Compression *QF*=75		Psychovisual Threshold *SF*=-25	
	40 Real Images	40 Graphic Images	40 Real Images	40 Graphic Images
DC Luminance	6.3715	5.968	5.7468	5.5237
DC Chrominance Cr	3.6904	4.5287	2.7175	3.8656
DC Chrominance Cb	4.0424	4.5336	3.0749	3.9670
AC Luminance	3.1136	3.3472	3.4937	3.8097
AC Chrominance Cr	2.0577	2.3590	1.8287	2.4832
AC Chrominance Cb	2.1931	2.4065	1.9418	2.5344

Table.2. Average Bit Length of Huffman Code of JPEG Image Compression Using Quality Factor *QF*=50 and Psychovisual Threshold *SF*=0.

Average bit length of Huffman Code	JPEG Compression *QF*=50		Psychovisual Threshold *SF*=0	
	40 Real Images	40 Graphic Images	40 Real Images	40 Graphic Images
DC Luminance	5.7468	5.5237	5.7468	5.5237
DC Chrominance Cr	2.7941	3.9660	2.7175	3.8656
DC Chrominance Cb	3.1548	4.0061	3.0749	3.9670
AC Luminance	2.8680	2.9993	2.7967	2.9637
AC Chrominance Cr	2.0951	2.4552	2.0721	2.3193
AC Chrominance Cb	2.1845	2.4823	2.1439	2.4014

Table.3. Average Bit Length of Huffman Code of JPEG Image Compression Using Quality Factor *QF*=25 and Psychovisual Threshold *SF*=25.

Average bit length of Huffman Code	JPEG Compression *QF*=25		Psychovisual Threshold *SF*=25	
	40 Real Images	40 Graphic Images	40 Real Images	40 Graphic Images
DC Luminance	4.8129	4.9254	5.7468	5.5237
DC Chrominance Cr	2.0249	3.1426	2.7175	3.8656
DC Chrominance Cb	2.2599	3.2909	3.0749	3.967
AC Luminance	2.5603	2.7586	2.6044	2.7051
AC Chrominance Cr	2.1251	2.4367	2.1176	2.2107

AC Chrominance Cb	2.0776	2.5404	2.1193	2.2788

To assess the quality of the image compression, the image reconstruction error shall be calculated by obtaining the differences between color image reconstruction $g(i, j, k)$ and original image $f(i, j, k)$. The image reconstruction error can be defined as follows:

$$E(s) = \frac{1}{3MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\sum_{k=0}^{2}\left|g(i,j,k) - f(i,j,k)\right|$$

The comparative image reconstruction error score between JPEG compression and psychovisual threshold at the respective quality factor are given in Table 4, 5 and 6.

Table.4. The Image Reconstruction Error Score of JPEG Image Compression Using Quality Factor QF=75 and Psychovisual Threshold SF= -25.

Image Measurement	JPEG Compression QF=75		Psychovisual Threshold SF= -25	
	40 Real Images	40 Graphic Images	40 Real Images	40 Graphic Images
Full Error	4.4492	4.1551	4.3966	4.2327
MSE	45.092	52.3127	43.948	52.9575
PSNR	33.4415	33.5977	33.4586	33.2559

Table.5. The Image Reconstruction Error Score of JPEG Image Compression Using Quality Factor QF=50 and Psychovisual Threshold SF=0.

Image Measurement	JPEG Compression QF=50		Psychovisual Threshold SF=0	
	40 Real Images	40 Graphic Images	40 Real Images	40 Graphic Images
Full Error	5.5349	6.1479	5.4987	5.8088
MSE	70.9636	113.8333	69.5203	100.0531
PSNR	31.1903	29.7903	31.2517	30.2278

Table.6. The Image Reconstruction Error Score of JPEG Image Compression Using Quality Factor QF=25 and Psychovisual Threshold SF=25.

Image Measurement	JPEG Compression QF=25		Psychovisual Threshold SF=25	
	40 Real Images	40 Graphic Images	40 Real Images	40 Graphic Images
Full Error	6.8019	7.9809	6.2508	6.8979
MSE	105.7614	190.0435	90.7582	142.1837
PSNR	29.1848	27.4205	29.9245	28.6063

Table.7. The Compression Ratio Score of JPEG Image Compression Using Quality Factor and Psychovisual Threshold.

JPEG Compression			Psychovisual Threshold		
Scale	40 Real Images	40 Graphic Images	Scale	40 Real Images	40 Graphic Images
QF= 75	3.213	2.9194	SF= -25	3.2738	2.6972
QF= 50	3.3247	2.9911	SF= 0	3.3882	3.0876
QF= 25	3.5297	3.0799	SF= 25	3.4708	3.2918

The experiment results show new custom quantization tables based on psychovisual threshold performs better than standard quantization table from JPEG compression at the respective quality factor. In order to visually observe image output, the image reconstruction is zoomed in to 400% as depicted in Figure 5. The experimental output image of an adaptive high compression rate using psychovisual threshold are shown on the right of Figure 6, Figure 7 and Figure 8.

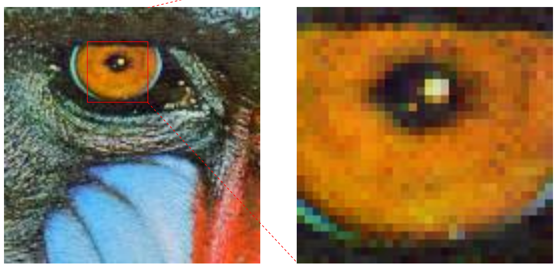

Fig.5. Original color image (left) and zoomed in to 400% (right).

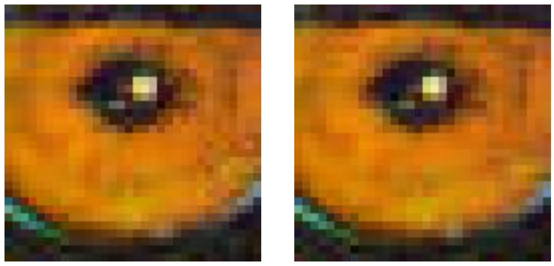

Fig.6. The comparison between JPEG quantization table with QF=75 (left) and psychovisual threshold with SF= -25 (right) zoomed in to 400%.

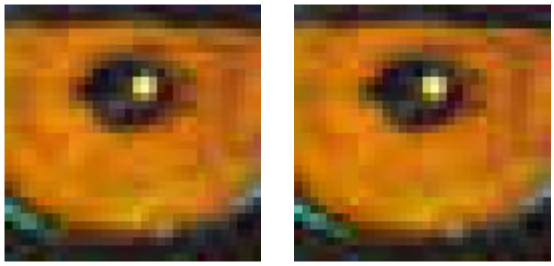

Fig.7. The comparison between JPEG quantization table with QF=50 (left) and psychovisual threshold with SF=0 (right) zoomed in to 400%.

Fig.8. The comparison between JPEG quantization table with QF=25 (left) and psychovisual threshold with SF=25 (right) zoomed in to 400%.

The popular quality factor in the extended JPEG image compression has been widely used to scale up the quantization table value. The scaling on the quantization tables increases their values uniformly thus produces high compression performance. The increasing quantization table value by a certain quality factor on JPEG

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compression may have not considered their effects to human visual system. While, the human visual system is more sensitive to change on low frequency signals which carry more significant visual information.

An adaptive psychovisual threshold is designed for custom quantization table generation based on human eye characteristics. The DC coefficient contains higher energy than AC coefficients. Recently, an experiment[11] has been done by taking only DC coefficient of 8×8 block making all AC coefficients zero. The DC coefficient represents important visual information of the image. The down scaling of the DC coefficient by large quantization table value can affect the significantly relevant image information.

The newly proposed technique based on an adaptive psychovisual model intends to produce optimal quantization tables for high image compression. The image reconstruction using an adaptive quantization based on psychovisual threshold performs better than uniform scaling quality factor from JPEG compression. Refer to Table 1, 2 and 3, the output images compression from adaptive quantization tables based on psychovisual threshold produce lower average bit length of Huffman code. At the same time, they produce lower reconstruction error than using scaling quality factors on JPEG quantization tables as presented in Table 4, Table 5 and Table 6. The visual quality inspection to the experimental results show a perceptually better quality on output image as depicted on the right of Figure 6, Figure 7 and Figure 8.

6. CONCLUSIONS

An adaptive JPEG image compression using psychovisual threshold has been investigated. The performance of the proposed adaptive JPEG image compression based on psychovisual threshold and the extended JPEG image compression using the quantization scaling factor have been compared. An adaptive quantization allows an image to be compressed at a better visual quality thus improving the compression rate. The experimental results of the new quantization tables based on psychovisual threshold produce an optimal quantization tables with higher quality image reconstruction at lower average bit length of Huffman code. This approach can be the next generation model to generate quantization tables for JPEG image compression especially on high compression rate.

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